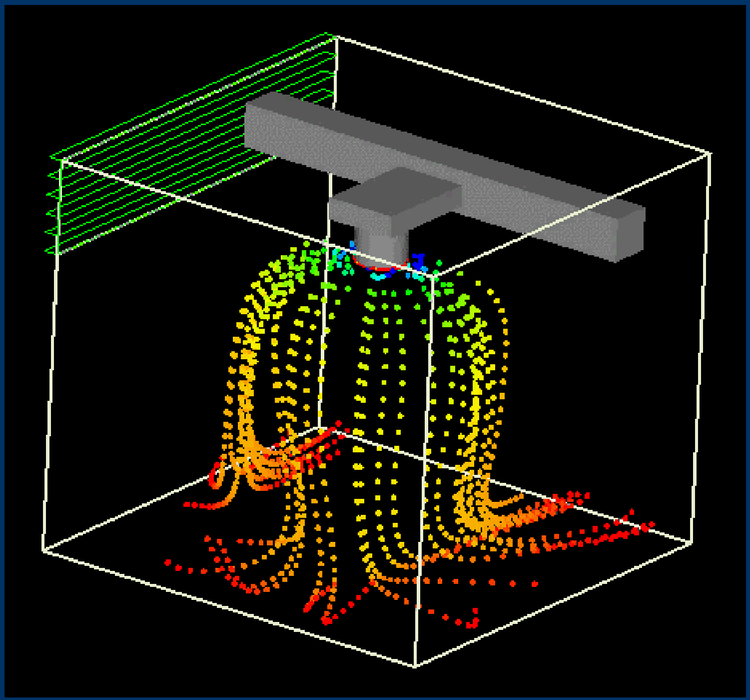
Airflow Modeling of Large Occupied Spaces



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Seminar 31: CFD Modeling of Large Occupied Indoor Spaces
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Ventilating Large Occupied Spaces

- Purposes of Ventilation
  - Indoor Air Quality
  - Comfort
  - Safety
- Applications
  - Arenas
  - Stadiums
  - Theaters
  - Auditoriums
  - Museums
  - Factories
  - Airports

Ventilation Concerns

- Places of assembly
  - indoor air conditions - ashrae comfort recommendations
- Museums, libraries, & archives
  - high relative humidity
  - temperature and humidity fluctuations
- Industrial environments
  - osha standards
  - heat removal and harmful contaminants

Why Perform Airflow Modeling?

- Investigate design performance ahead of time -

  large spaces are expensive to fix after built

- Demonstrate to clients and other involved parties how different ventilation strategies work so that they may better evaluate performance vs. cost issues

- Better understand alternatives to mixing ventilation

  displacement ventilation / radiant cooling / natural ventilation

- Streamline diffuser placement avoiding high velocities and non-uniform temperature distributions in occupied zones

What is Airflow Modeling

- Numerical approach to solve the complex governing equations of airflow
  continuity / momentum / energy / contaminant transport
- Requires discretizing a computer model of the space -> mesh
  not all features of the geometry are relevant to airflow
- Requires specification of boundary conditions
  flows / heat sources / contaminant sources / wall BCs

Boundary Conditions

- Ventilation system
  - location, types, and performance characteristics of inlet diffusers and exhausts

  flow rates / temperature / humidity / contaminant level

- Thermal loads

  occupants / lighting / equipment

- Contaminant sources

  location / type / strength

- Building heat loads

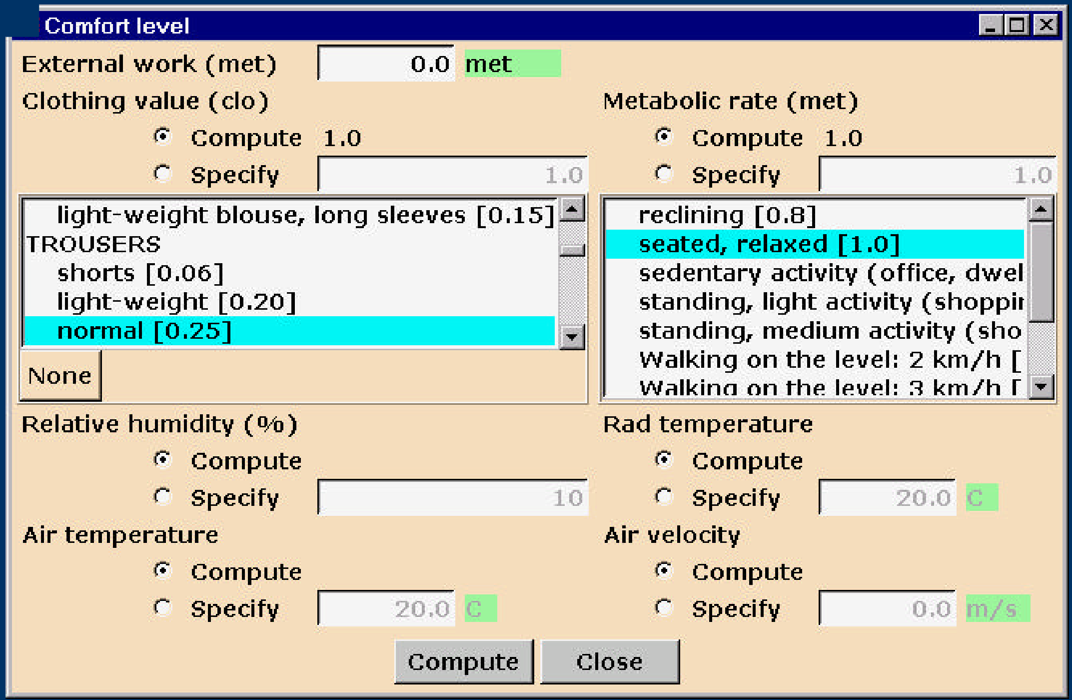
Physical Models

- Turbulence
  - unsteady, aperiodic motion in which all three velocity components fluctuate → mixing matter, energy, momentum, and contaminants
  - time-averaged statistics of turbulent velocity fluctuations are modeled using functions containing empirical constants and information about the mean flow

- Radiation
  - Radiative heat flux between surfaces depends on
    - → surface temperature
    - → surface emissivity
    - → form factor from one surface to the other
  - Since air velocities are relatively low, heat transfer is dominated by natural convection and radiation

Thermal Comfort Predictions

- Various methods to estimate perceived thermal comfort are available



- Methods can use information from airflow modeling simulations to compute comfort

  - design input
    - → metabolic rate
    - → clothing assumptions
  - local info needed from simulation
    - → relative humidity
    - → air temperature
    - → air velocity
    - → mean radiant temperature

Special Considerations

- Mesh size - turnaround time proportional to mesh size
  - large physical space implies a large number of computational cells will be necessary
  - complex geometries and/or numerous interior objects will also demand more computational cells

- Unstable airflow patterns
  - buoyancy effects + large spaces -> high Rayleigh numbers - difficult to obtain converged steady-state solutions because real-life airflow patterns may not be stable

Archimedes and Rayleigh Numbers

$$\mathrm{Ar} = \frac{\mathrm{Gr}}{\mathrm{Re}^2} = \frac{gb\Delta TL}{U^2}$$

Strength of natural convection compared to forced convection

$$\mathrm{R}a = \frac{gb\Delta TL^3}{na}$$

Related to likelihood of instabilities leading to chaotic motion

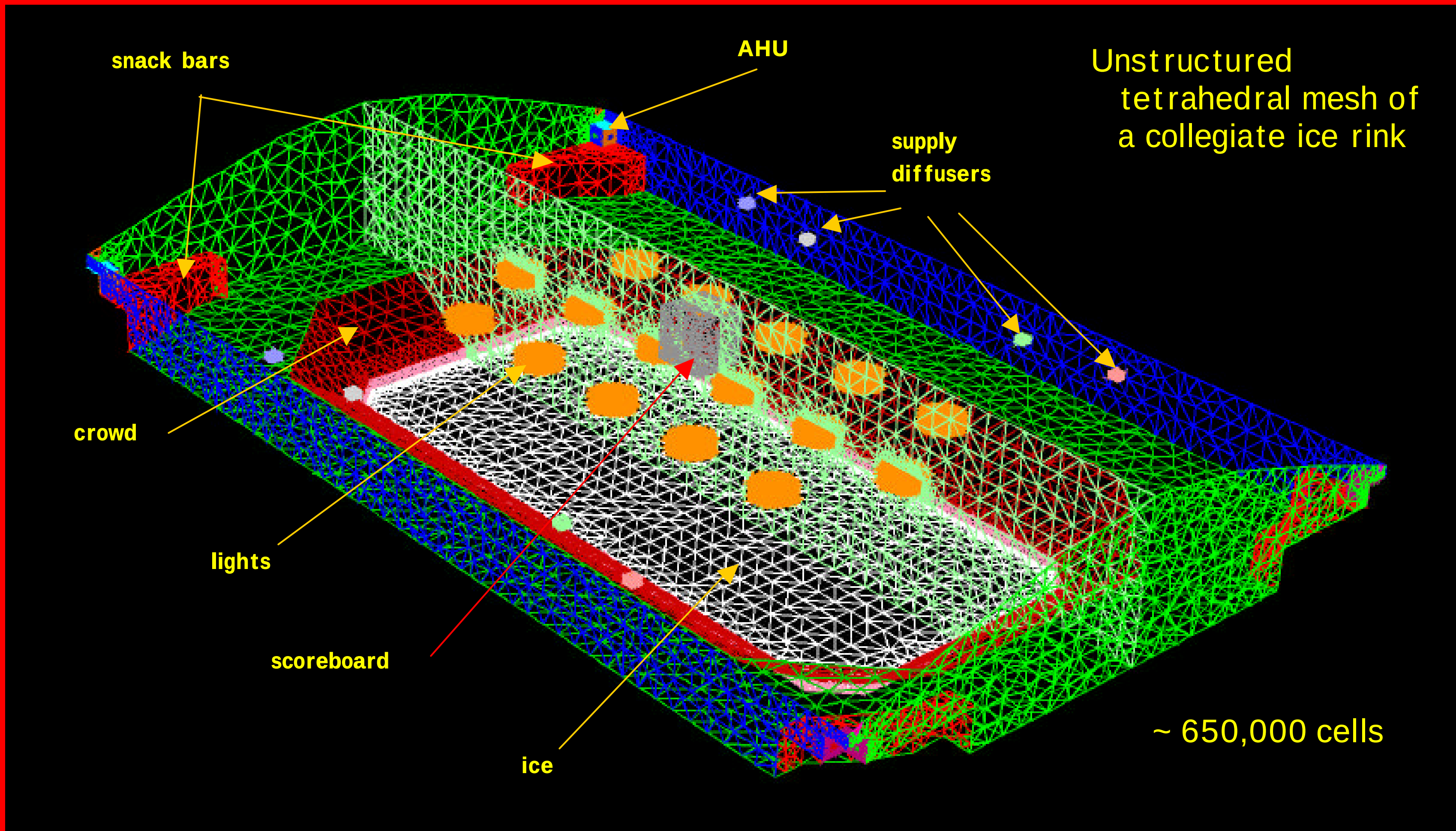
Ventilation of an Ice Rink

- Modeled interior region of a collegiate ice rink
- Boundary conditions:
  - airflow
  - occupancy
  - lighting heat loads
  - other heat loads
  - walls

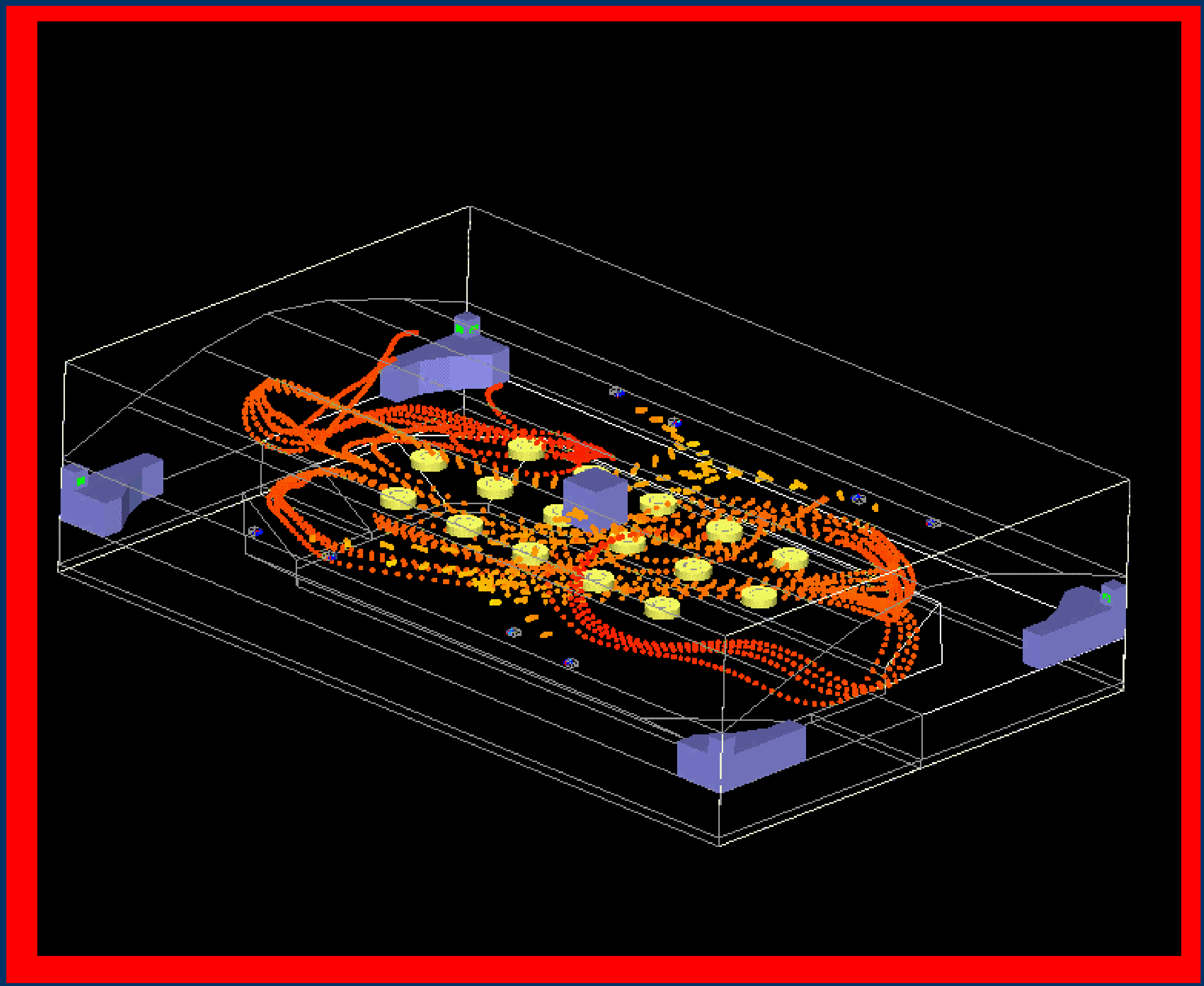
- 1.1 ACH
- Archimedes No. = 2.4
- Rayleigh No. = 10^12

- heat load - 237 kW
  - occupants - 70%
  - lighting - 27%
  - other - 3%

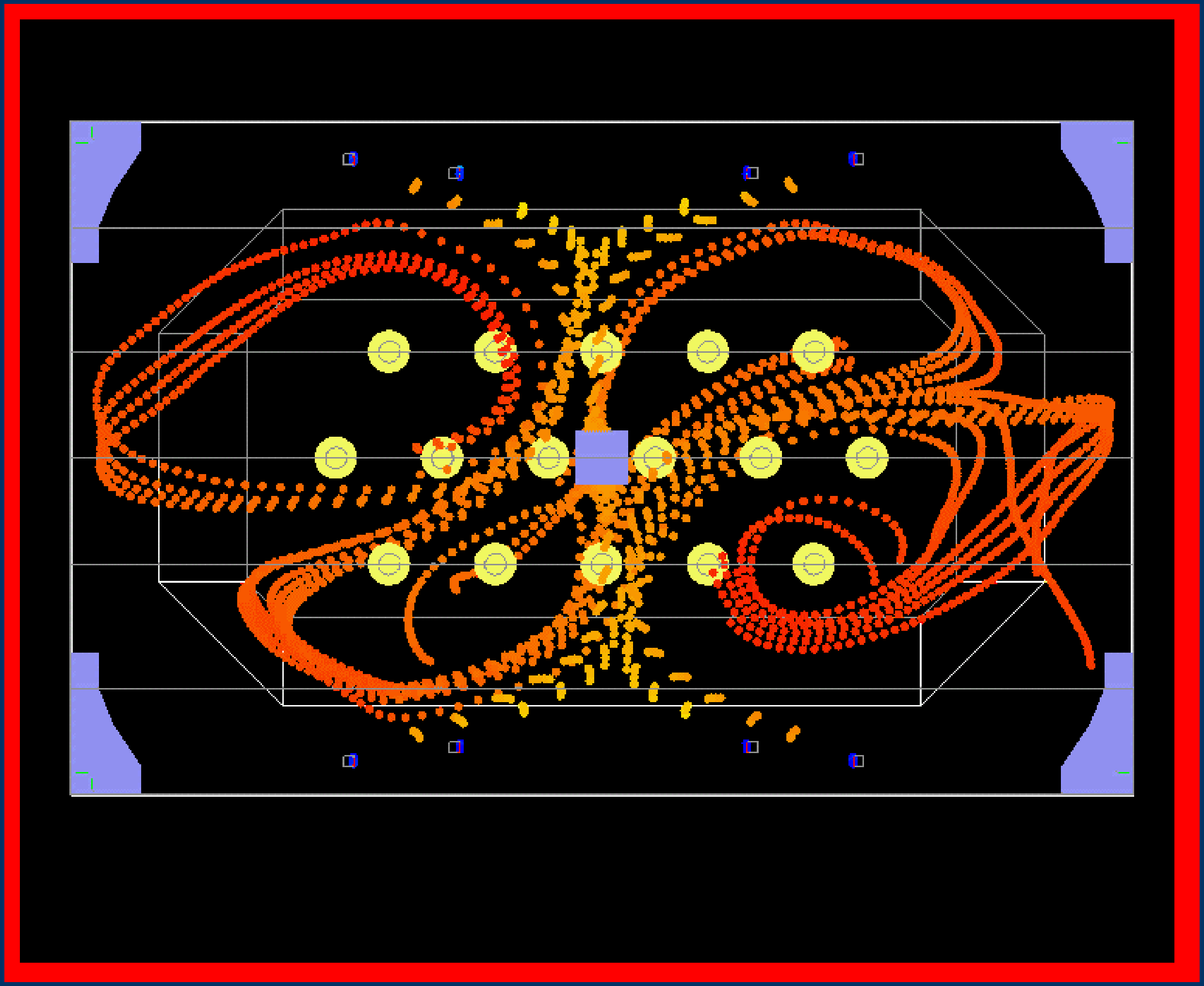
Computational Mesh

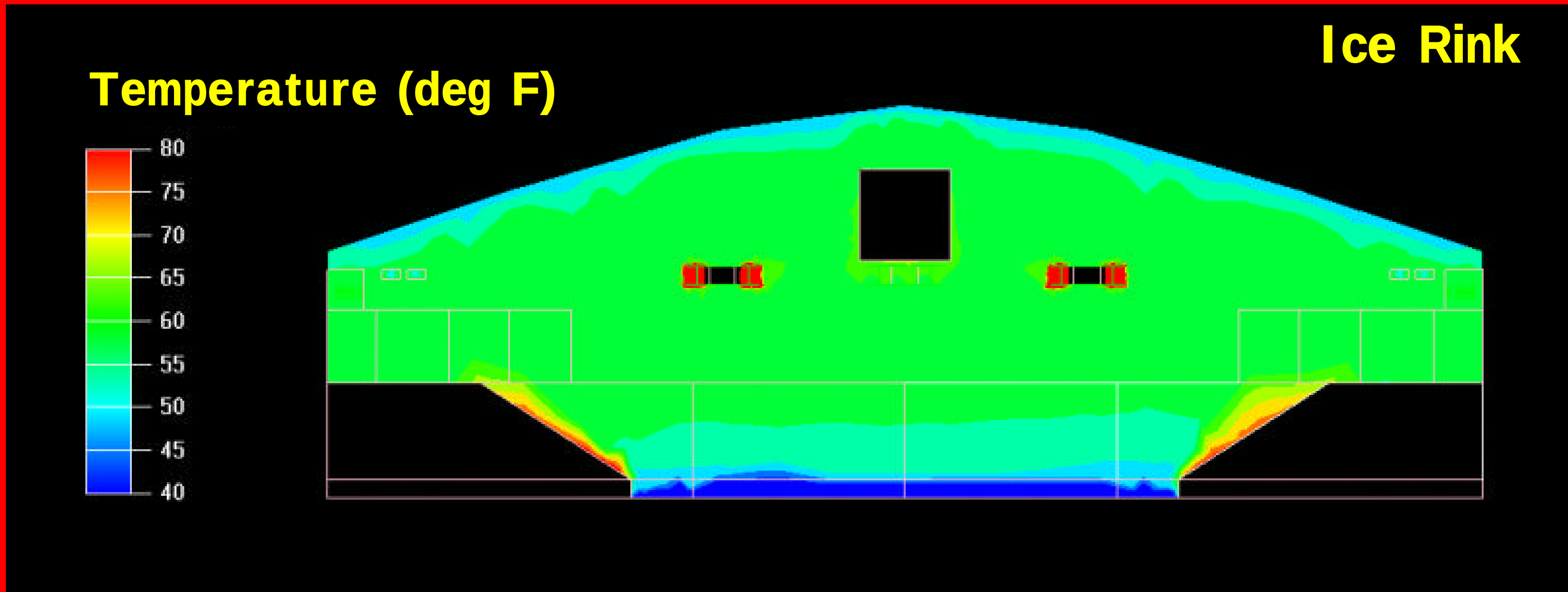


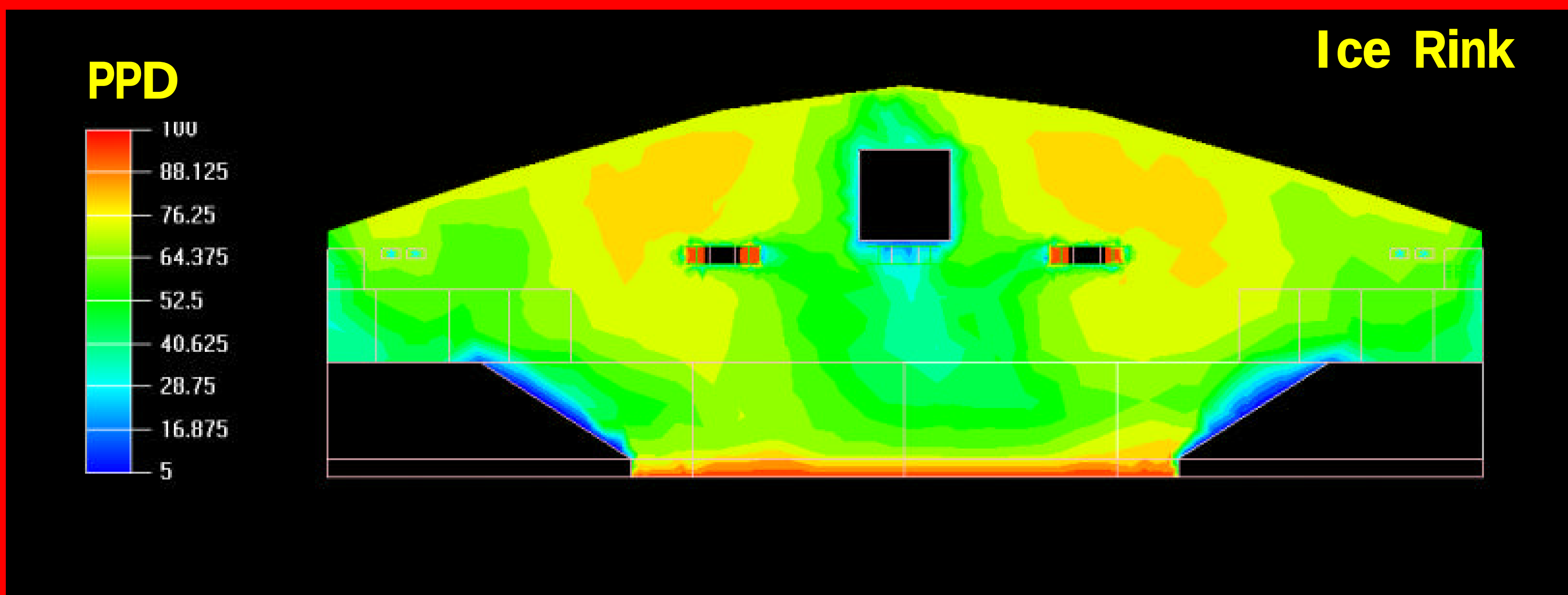
Airflow Patterns in an Ice Rink



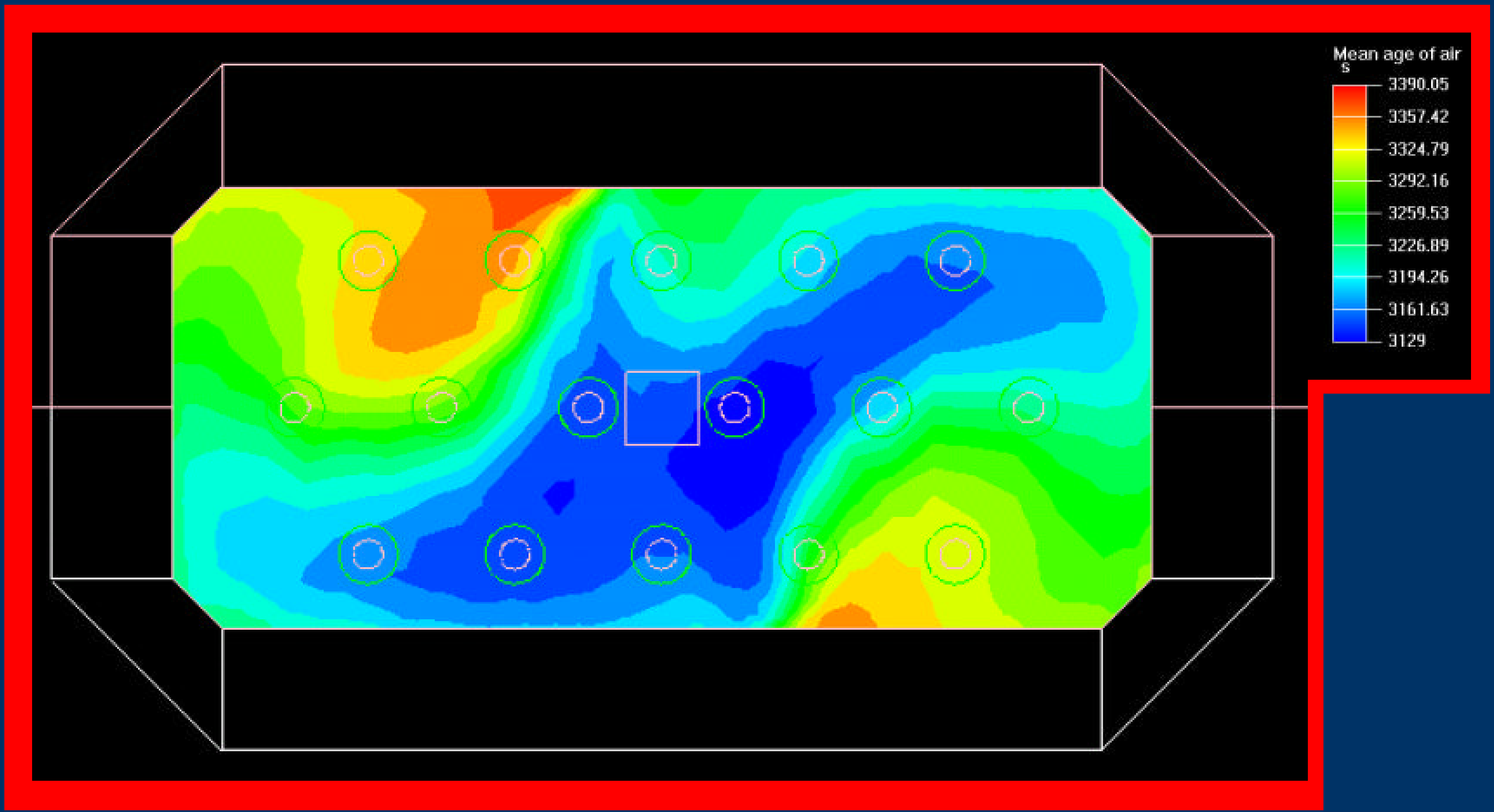
Airflow Patterns in an Ice Rink




Ice Rink
Temperature (deg F)
80
75
70
65
60
55
50
45
40

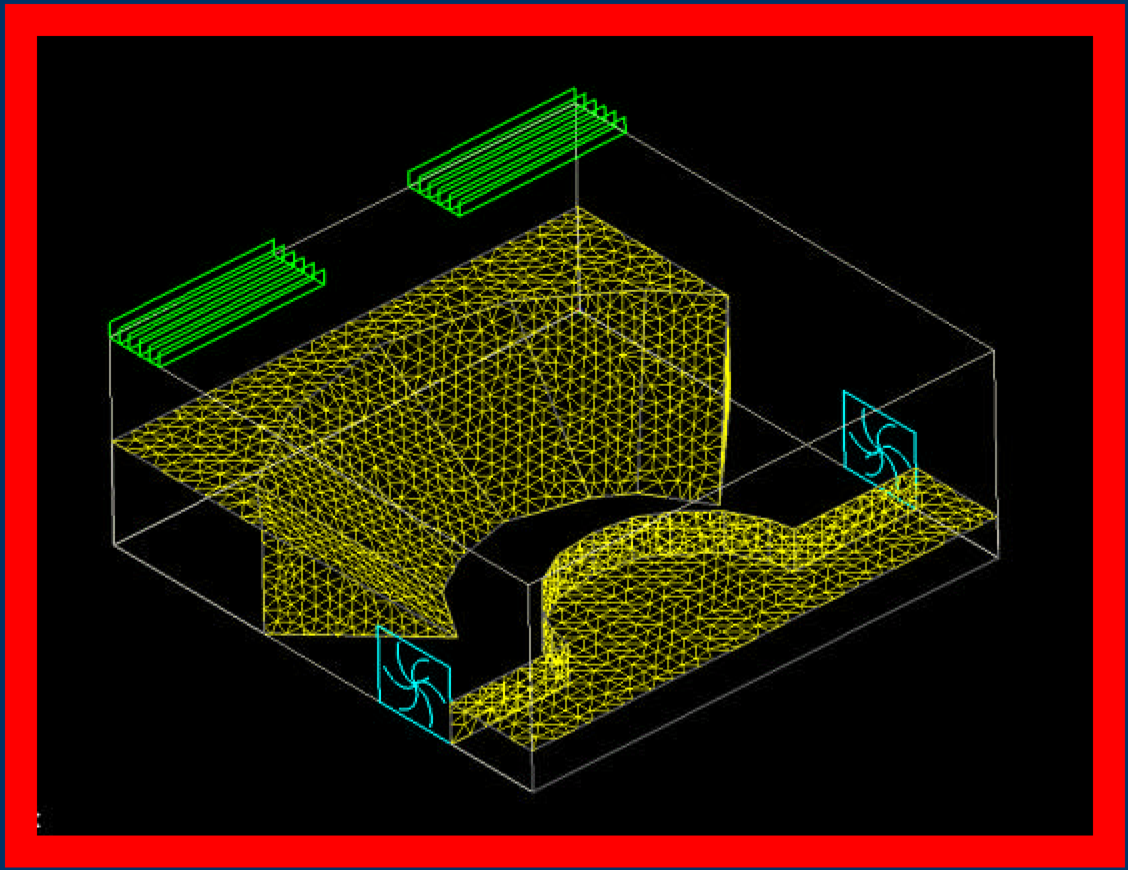

Ice Rink
PPD
100
88.125
76.25
64.375
52.5
40.625
28.75
16.875
5

Mean Age of Air at Skating Surface



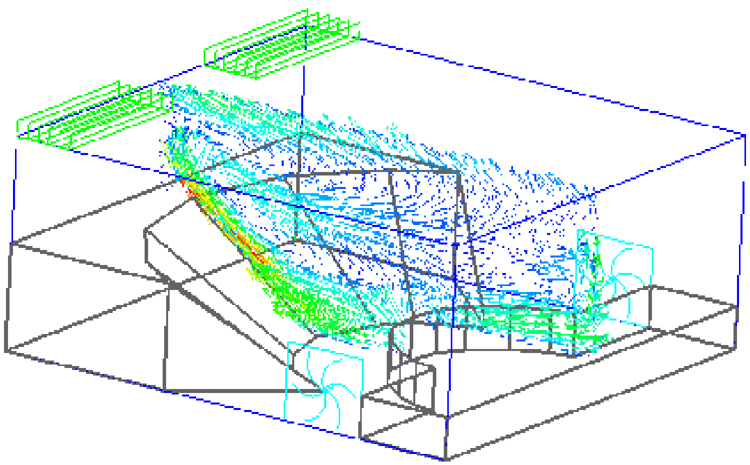
School Auditorium Displacement Ventilation

- Modeling airflow patterns and predicting thermal comfort helps allow architects and engineers to explore new ventilation approaches

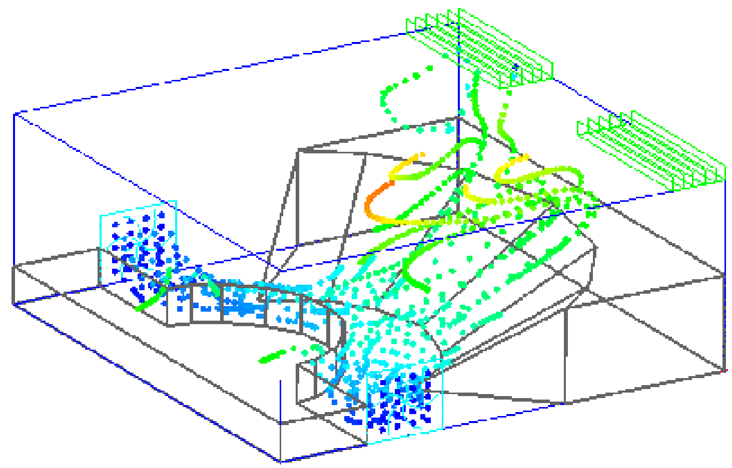


- 2.6 ACH
- Archimedes No. = 600
- Rayleigh No. = 10^12
- heat load - 90 kW
  - occupants - 70%
  - lighting - 30%

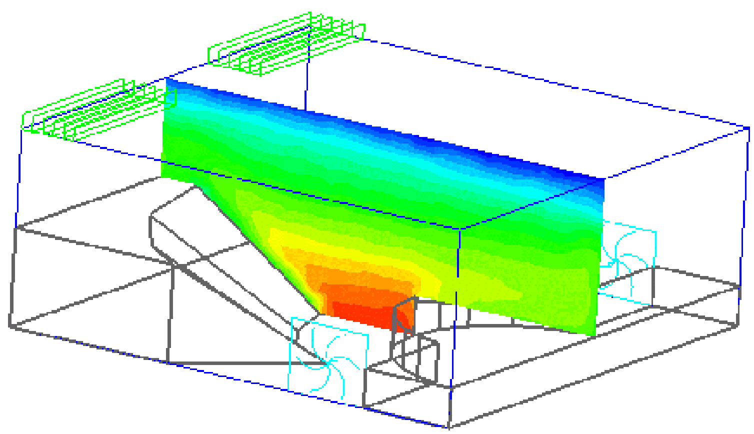
School Auditorium Displacement Ventilation



airflow velocity vectors



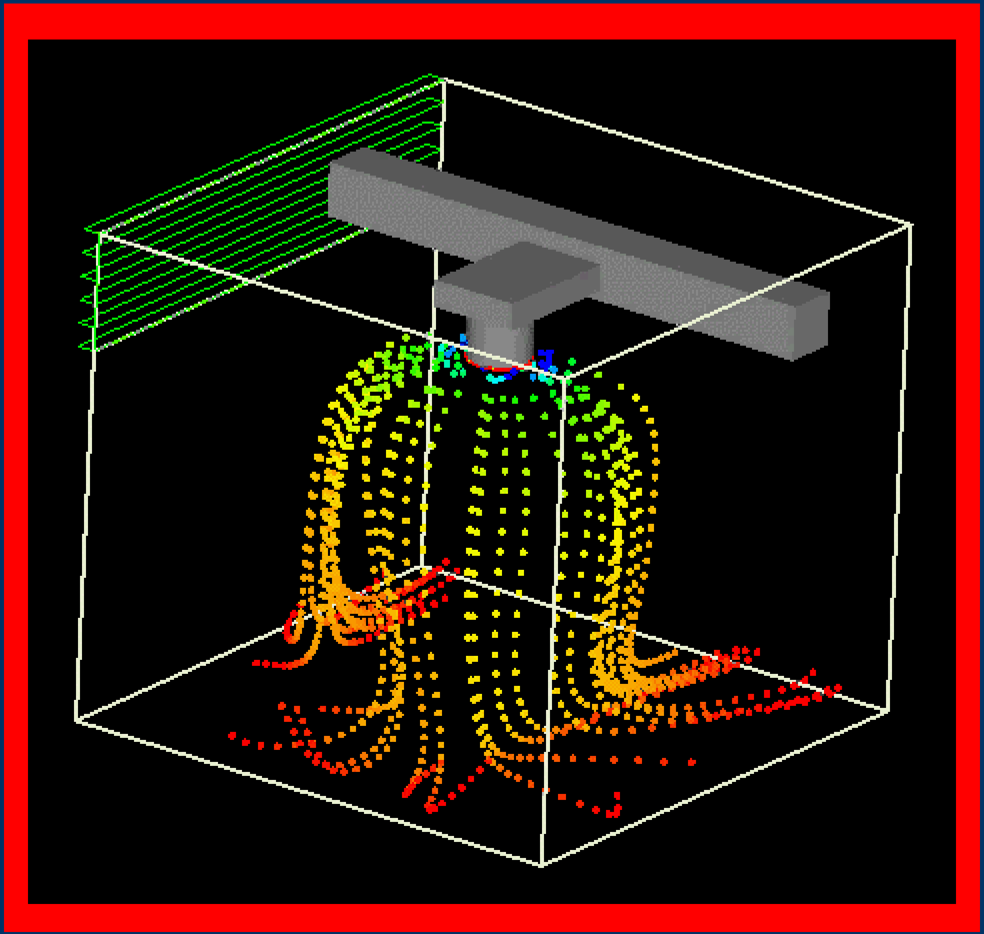
particle traces colored by temperature



relative humidity

Cooling Ventilation of Exhibition Space

- Circular ceiling diffuser supplies cool air for occupant comfort in a large 60'x54'x60' section of an exhibition space
- Model included loads from overhead lighting as well as occupants
- Symmetry accounted for on two vertical surfaces
  - 2.2 ACH
  - Archimedes No. = 1.1
  - Rayleigh No. = 10^13
  - heat load - 43 kW
    - occupants - 87%
    - lighting - 4%
    - other - 9%



particle traces colored by temperature

Accuracy

- Convergence does not guarantee accuracy

- Accuracy depends on
  - numerical scheme: 2nd-order is more accurate than 1st-order
  - resolution of the mesh: grid-independent solutions are desired
  - accuracy of boundary conditions
  - accuracy of physical models (i.e., turbulence models)
  - accuracy of modeling assumptions
    - →setting up the geometry
    - →modeling various processes (i.e., smoke from a fire)

Summary

- Large occupied spaces are inherently large financial projects for which designers need to determine a priori how well the proposed ventilation system will perform

- Airflow modeling can be used in design phase
  - airflow velocity distribution
  - temperature distribution
  - relative humidity distribution
  - thermal comfort predictions